

A PHYSICAL INTERPRETATION OF MOND

D.V. Bugg¹

Department of Physics, Queen Mary, University of London, London E1 4NS, UK

Abstract

Earlier comparisons of galactic rotation curves with MOND have arrived at the conclusion that the parameter a_0 lies within $\sim 20\%$ of $cH_0/2\pi$, where c is the velocity of light and H_0 is the Hubble constant. It is proposed here that, for this value of H_0 , signals propagating around the periphery of the Universe are phase locked by the graviton-nucleon interaction.

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1 Introduction

MOND (Modified Newtonian Dynamics), is an empirical scheme invented by Milgrom in 1983 [1], [2] to account for what was then known about rotation curves of galaxies from the work of Tully and Fisher [3]. Famaey and McGaugh have reviewed all aspects of the data with an exhaustive list of references [4].

In MOND, the observed total acceleration A is related to Newtonian acceleration g_N by

$$A = g_N / \mu(\chi) \quad (1)$$

where μ is a smooth fitting function, $\chi = A/a_0$ and a_0 is a universal constant with a value $\sim 1.2 \times 10^{-10} \text{ m s}^{-2}$ for all galaxies. There are three forms in common use. All three tend to $A = \sqrt{a_0 g_N}$ for small g_N . The most symmetrical is

$$\mu = \sqrt{1 + \frac{a_0^2}{4A^2}} - \frac{a_0}{2A}. \quad (2)$$

Re-arranging this expression and equation (1)

$$(g_N/A + a_0/2A)^2 = 1 + (a_0/2A)^2 \quad (3)$$

$$g_N^2 + a_0 g_N = A^2. \quad (4)$$

A star with rotational velocity v in equilibrium with centrifugal force obeys

$$v^2/r = \sqrt{a_0 G M}/r; \quad (5)$$

G is the gravitational constant and M the galactic mass within radius r ; the factor r cancels and the Tully-Fisher relation emerges:

$$v^4 = a_0 G M. \quad (6)$$

Famaey and McGaugh show examples comparing this relation with rotation curves in their Figs. 24 to 27. McGaugh demonstrated that galaxies with well determined rotational velocities follow the Tully-Fisher relation accurately over 5 decades of galactic mass [5].

In a later paper, McGaugh concludes that gas-rich galaxies give the best determination of baryonic masses of galaxies, with the result $a_0 = (1.113 \pm 0.3) \times 10^{-10} \text{ m s}^{-2}$ [6]. Gentile, Famaey and de Blok found $1.122 \pm 0.33 \times 10^{-10} \text{ m s}^{-2}$ [7].

¹david.bugg@stfc.ac.uk

2 The relation of a_0 to the Hubble Constant

The radius of the Universe is given by the Hubble length $r = c/H_0$. At the velocity of light, signals propagating round the periphery of the Universe in any direction take time $2\pi c/H_0$ to complete one orbit. The parameter H_0 has the dimensions s^{-1} , with the result that $2\pi c/H_0$ has the dimensions of acceleration, as does a_0 . Gravitational waves propagating round the periphery of a spherical Universe in all directions then arrive in phase. Fig. 1 shows the observed variation in galaxies between the total acceleration A and Newtonian acceleration g . The conclusion was reached in an earlier paper [8] that galaxies are Fermi-Dirac condensates in the graviton-nucleon interaction. Consider gravitons arriving at the edge of a galaxy and distributed around an axis running from the periphery of the galaxy to its centre. These gravitons have very long wavelengths and can interfere coherently with stars and clusters of stars over a very large volume. The overall result is given by the *intensity* of this interaction acting as an amplifier. The result may be fitted by an Airy disc with an adjustable radius parameter.

As aside is that there was one unfortunate error of wording in Ref. [8]. The text referred to the Hubble acceleration; this should read Hubble constant. It has no effect on conclusions in that paper.

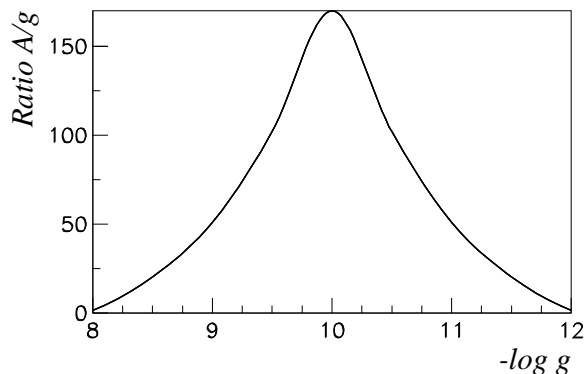


Figure 1: The observed ratio between total acceleration A and Newtonian acceleration g .

My proposal is that the same mechanism operates in the graviton-nucleon interaction on the scale of the Universe. There are inhomogeneities in the Universe, notably the Sloan Great Wall. This will induce a similar shape to that in Fig. 1. We can only see such features as they were a long time ago. They will change with time as galaxies evolve and crash into one another. The fact that the Universe is round suggests that effects of this evolution are damped oscillations. The inference is that the parameter a_0 originates from the curvature of space. If H_0 changes, my prediction is that a_0 will change with it.

3 An important comment on how to fit the Cosmic Microwave Background

There is an important result from a paper of Milgrom on weak gravitational lensing of galaxies [9] using data of Brimiouille et al. [10]. They have examined foreground galaxies illuminated by

a diffuse background of distant galaxies. They removed signals from the centres of foreground galaxies so that their edges and haloes could be studied. Their objective was to study the Dark Matter halo. The asymptotic form $\sqrt{a_0 g}$ of the acceleration varies as $1/r$; integrating this term leads to a logarithmic tail $V(r) = -\sqrt{GMa_0} \ln_e(r/r_0)$ to the Newtonian potential; here r_0 is the mean radius for this term. Milgrom transforms this into the variables used by Brimiouille et al. He shows that their results obey MOND predictions accurately over a range of accelerations $10^{-9} - 10^{-11} \text{ m s}^{-2}$. Averaged over this range, results are a factor ~ 40 larger than predicted by conventional Dark Matter haloes surrounding galaxies. Fig. 1 shows the ratio of observed acceleration A to Newtonian acceleration as a function of $x = -\log_{10} g_N$. At the peak acceleration a_0 , the effect is larger than Dark Matter predicts by a factor ~ 65 . The conclusion is that the standard Λ CDM model needs serious modification.

There are two sources of information on H_0 and its variation with time. One is the observed variation of type 1a supernovae as a function of red-shift z . The second is the map of temperature fluctuations observed over the visible Universe. This spectrum is expressed as a series of Spherical Harmonics up to angular momentum $L \simeq 2500$. Peaks appear in the spectrum beginning at $L \simeq 220$ and falling as $L \rightarrow 2500$. A critical issue is how to interpret this spectrum.

The recombination of hydrogen atoms after the Big Bang occurred over a volume with a diffuse edge. The slope of this edge governs the magnitudes of successive peaks between $L = 220$ and 2500. It arises from damping of the power spectrum at high L values due to photon diffusion from high temperature regions to cooler regions, Silk damping [11]. In the correlations of temperature T in the data published recently by the Planck collaboration [12], there is a contribution from correlations TT in the Baryon Acoustic Oscillations and also E- and B-mode polarisations. Formulae are given in Section 8.7 of a paper by Straumann [13] and have been used by the Planck collaboration. A recent paper of Schmittfull, Challenor, Hanson and Lewis [14] reviews in detail the fit to data.

However, there is a serious point which has been overlooked. A corollary follows from Milgrom's fit to the data of Brimiouille et al. which agree with MOND, but are far from the prediction of Λ CDM. Here the photons come from distant galaxies. The Baryonic Acoustic Oscillations are likewise carried by photons, which in this case originate from the Cosmic Microwave Background. These must be treated in the same way. The conventional assumption made in the work of Ref. [14] is that photons from the Cosmic Microwave Background are bent in weak gravitational lensing only by Newtonian dynamics (including small corrections for General Relativity). However, since MOND fits the data of Brimiouille et al. but Λ CDM does not by a large margin, the astrophysics community should be alert to the fact that an additional energy $-\sqrt{GMa_0} \ln_e(r/r_0)$ originates from integrating the acceleration $\sqrt{GMa_0}/r$; r_0 is the radius where the acceleration is a_0 . This is needed over the range of accelerations where MOND explains the gravitational rotation curves, see Figure 1. It is not presently included in the fit to the Baryonic Acoustic Oscillations but needs to be.

It is now well established that there is a cosmic web of filaments, galaxies and voids on the scale of the Universe. These appear in WMAP data on very large scales, corresponding to an angular dependence $L \leq 10$ on the scale of the Universe [15]. Two recent papers on the cosmic web are by Alpaslan et al. [16] and Cantun et al. [17]. My proposal is that these structures arise from the graviton-nucleon interaction on the scale of the Universe.

4 Conclusions

The primary conclusion is based on the fact that the parameter a_0 of MOND agrees with $cH_0/2\pi$. It may be understood as arising from the graviton-nucleon interaction. It was proposed earlier [8] that galaxies are Fermi-Dirac condensates formed in this interaction. Here it is proposed that the same graviton-nucleon interaction operates on the scale of the Universe and leads to phase-locking of signals propagating round the periphery of the Universe in any direction, hence the shape of the curve in Fig. 1.

A second point is that the Cosmic Microwave Background needs to be fitted including a correction which derives from an additional energy $-\sqrt{GMa_0 \ln_e(r/r_0)}$ which is presently missing from equations for the Cosmic Microwave Background.

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